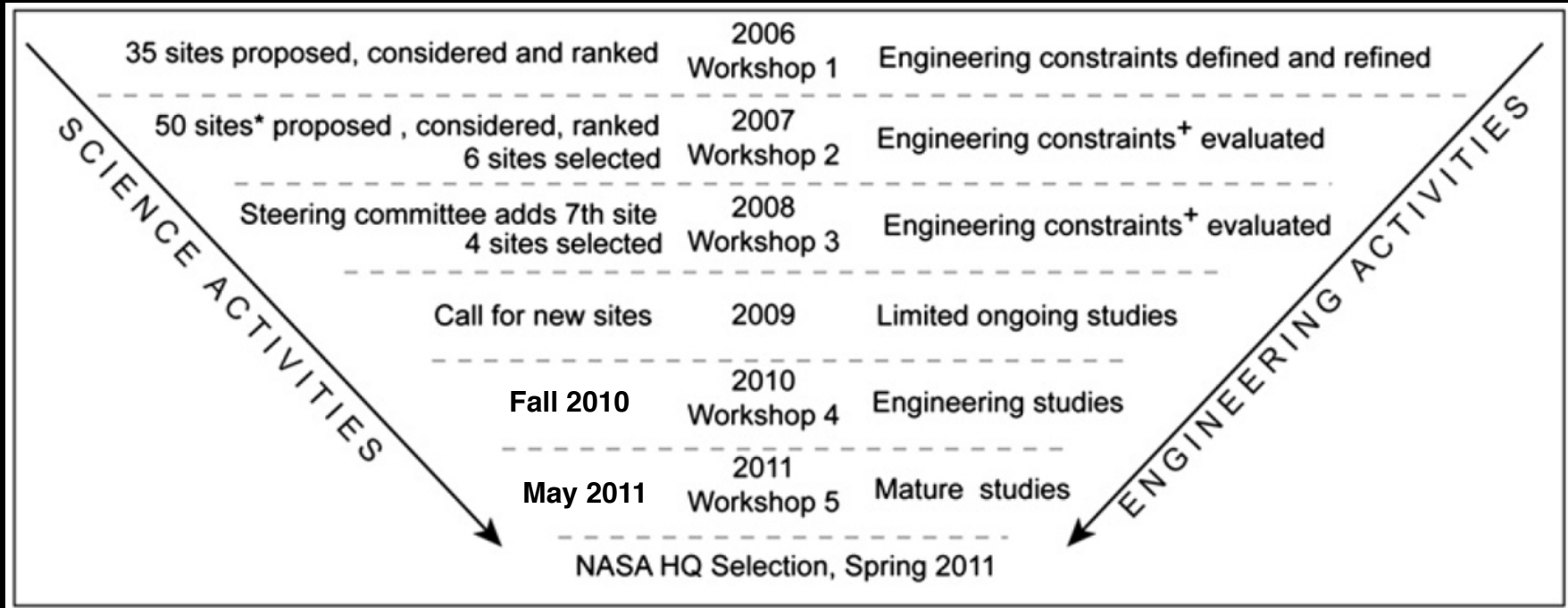


MSL Landing Site Selection Activities:

Mars Landing Site Selection Activities

A Relatively Long and Occasionally Strange Trip...

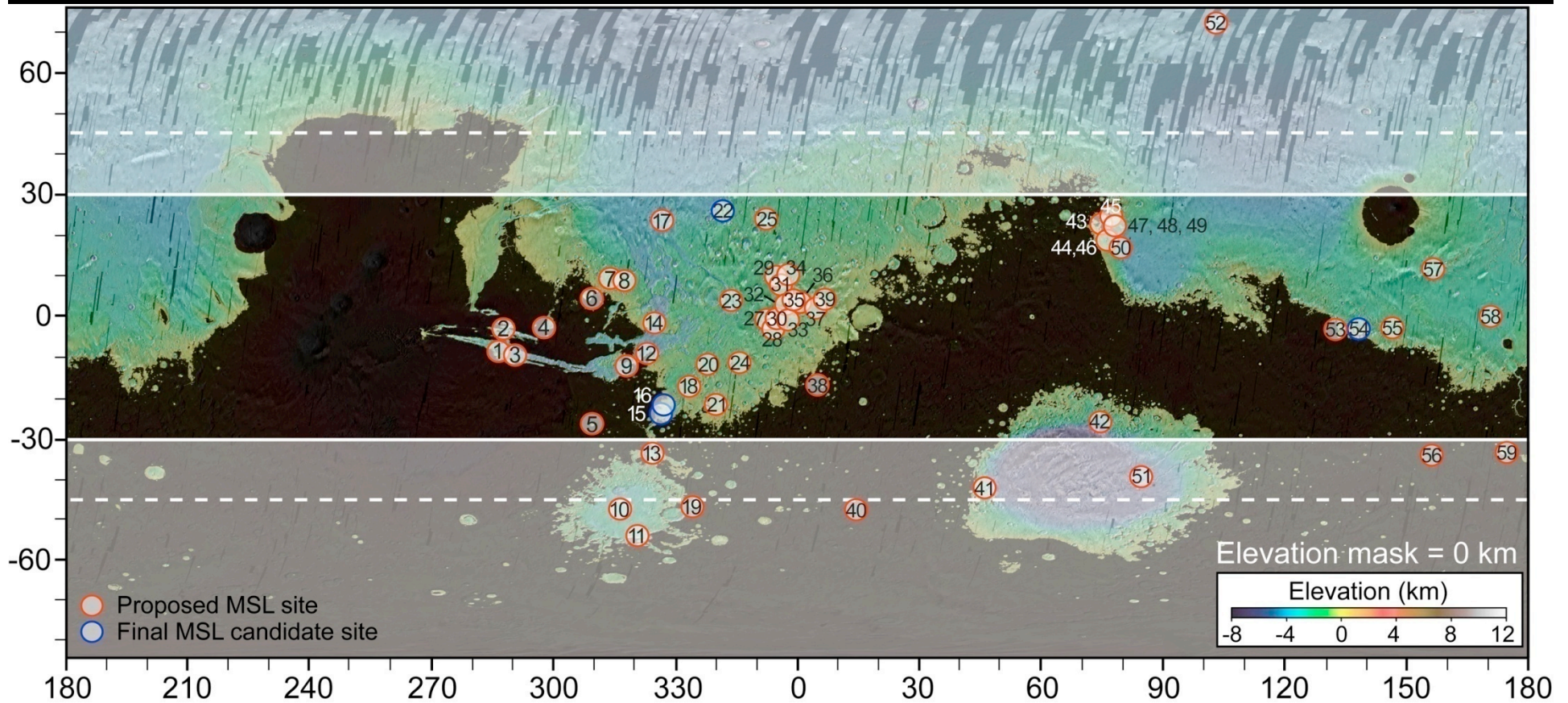


...But Remarkably Comprehensive and Scientifically Rich

John Grant, Smithsonian Institution

Proposed MSL landing sites:

Mars Landing Site Selection Activities



Shaded areas are above +30°N, below -30°S, and above 0 km in elevation

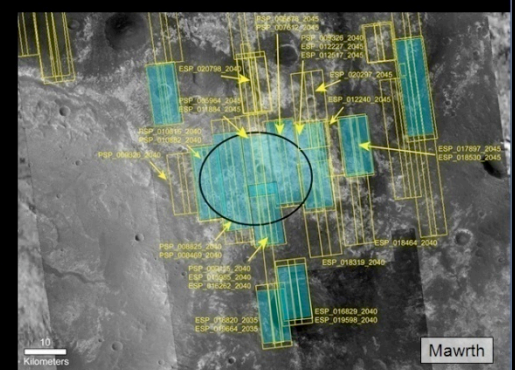
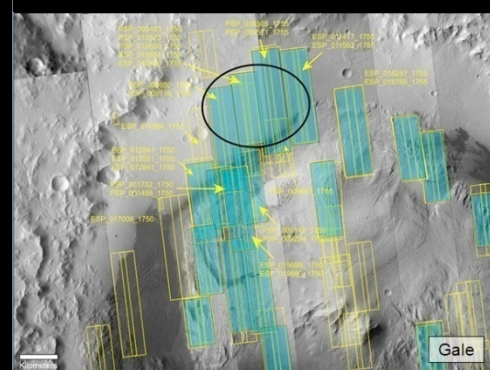
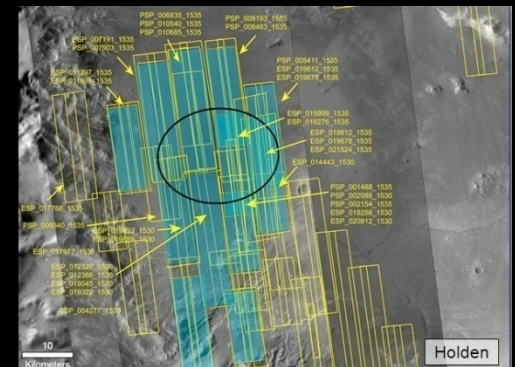
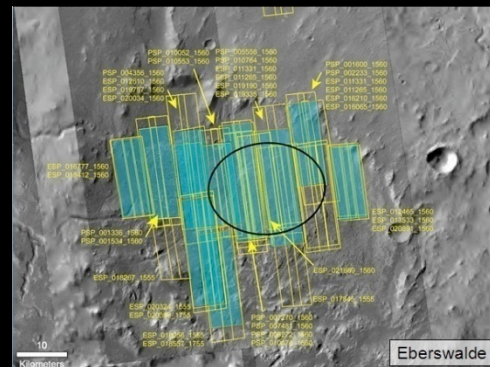
Evaluating Candidate MSL Landing Sites:

Mars Landing Site Selection Activities

Current orbital assets have set the new standard for data required for identifying and qualifying new Mars landing sites

An incredible effort by instrument teams has gone into obtaining high quality data used to evaluate candidate sites

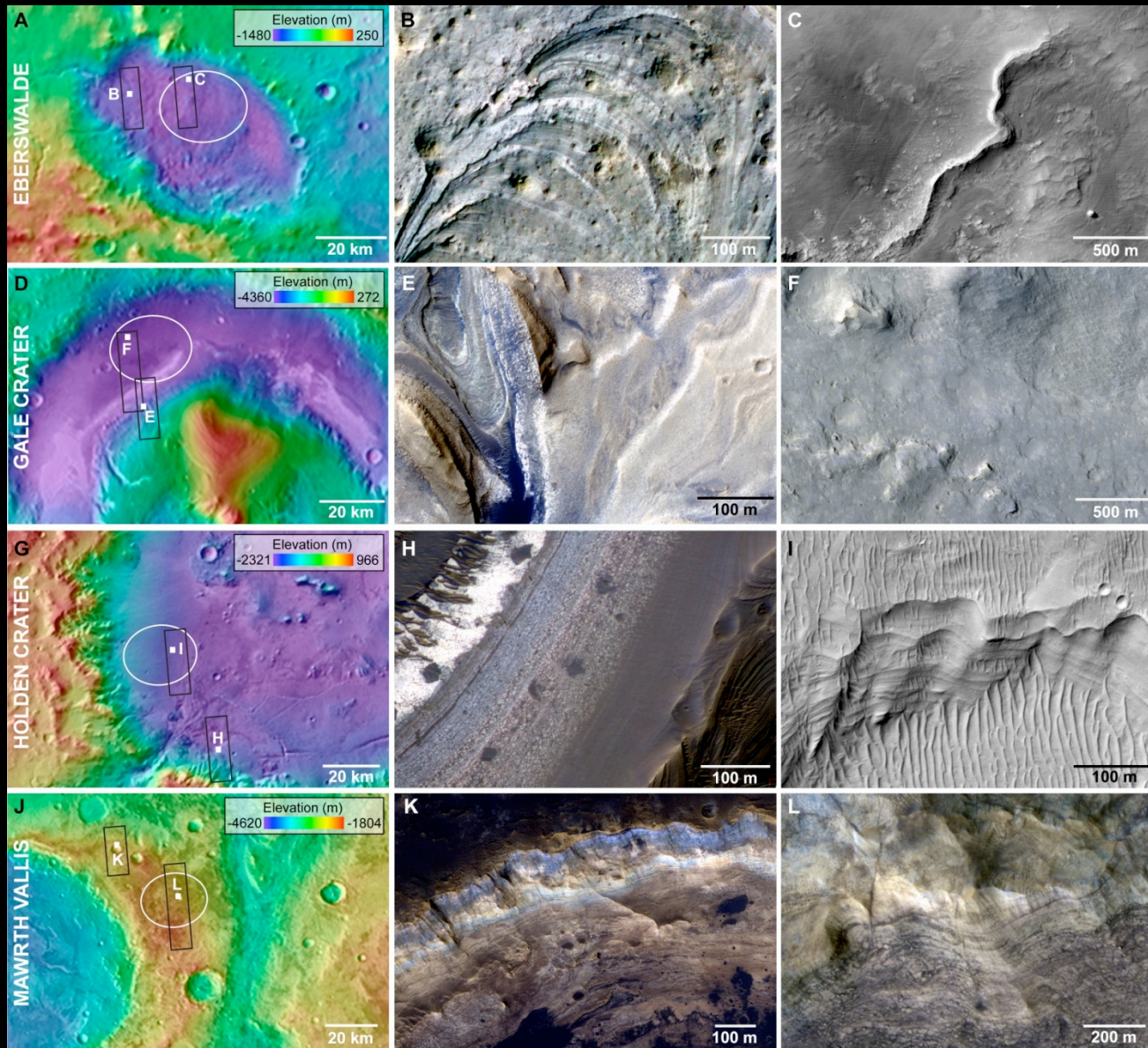
VIKING	Pathfinder	MER	MSL
			HIRISE
			CRISM
			CTX
			MCS
			MER
			SHARAD
			MARSIS
			OMEGA
			HRSC
		THEMIS	THEMIS
		MOC	MOC
		TES	TES
		MOLA	MOLA
		Pathfinder Site	Pathfinder Site
	Viking Landing Sites	Viking Landing Sites	Viking Landing Sites
	Earth-based Radar	Earth-based Radar	Earth-based Radar
Viking IRTM	Viking IRTM	Viking IRTM	Viking IRTM
Viking Images	Viking Images	Viking Images	Viking Images



More than 200 MRO Observations of Candidate Landing Sites to Date!

Overview of the Final Four Candidate Landing Sites:

Mars Landing Site Selection Activities



Each of the final four sites represents an exciting science target

Records of the Science Process:

Mars Landing Site Selection Activities



The science process for selecting the landing site for the 2011 Mars Science Laboratory

John A. Grant^{a,*}, Matthew P. Golombek^b, John P. Grotzinger^c, Sharon A. Wilson^a, Michael M. Watkins^b, Ashwin R. Vasavada^b, Jennifer L. Griffes^c, Timothy J. Parker^b

^a Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, 9th & Independence SW, Washington, DC 20580, USA

^b Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA

^c Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA

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ABSTRACT

The process of identifying the landing site for NASA's 2011 Mars Science Laboratory (MSL) began in 2005 by defining science objectives, related to evaluating the potential habitability of a location on Mars, and engineering parameters, such as elevation, latitude, winds, and rock abundance, to determine acceptable surface and atmospheric characteristics. Nearly 60 candidate sites were considered at a series of open workshops in the years leading up to the launch. During that period, iteration between evolving engineering constraints and the relative science potential of candidate sites led to consensus on four final sites. The final site will be selected in the Spring of 2011 by NASA's Associate Administrator for the Science Mission Directorate. This paper serves as a record of landing site selection activities related primarily to science, an inventory of the number and variety of sites proposed, and a summary of the science potential of the highest ranking sites.

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1. Introduction

The selection of the landing site for the National Aeronautics and Space Administration (NASA) 2011 Mars Science Laboratory (MSL) rover plays a crucial role in the success of the mission. Although this paper emphasizes science activities related to selection of the MSL landing site, a myriad of orbital datasets from multiple missions were utilized to characterize each potential landing site from a science and engineering standpoint. The objective of all landing site activities is to maximize the chance of landing safely with access to high-priority science targets.

Science and engineering characterization of the landing sites emphasizes data from the Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Imaging Spectrometer for Mars (CRISM, see Murchie et al., 2007), High Resolution Imaging Science Experiment (HiRISE, see McEwen et al., 2007), and Context Camera (CTX, see Malin et al., 2007) instruments, Mars Odyssey Thermal Emission Imaging System (THEMIS, see Christensen et al., 2004) instrument, Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC, see Malin et al., 1992), Mars Observer Laser Altimeter (MOLA, see Zuber et al., 1992), and the Mars Express Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité

(OMEGA, Bibring et al., 2004) spectrometer and High Resolution Stereo Camera (HRSC, Jaumann et al., 2007).

The safe delivery of MSL to Mars' surface also depends upon the characterization of the atmosphere through which the spacecraft flies. The MSL spacecraft's entry, descent, and landing system involve a guided entry, parachute deployment, and a rocket-powered terminal descent to the surface. A team of atmospheric scientists has been advising the mission and providing model-based predictions of atmospheric density, winds, and the probabilities and effects of dust storms at the MSL arrival season. These atmospheric assessments will be described in a separate publication; here we focus on the terrain.

The inferred geologic setting of the site must lend confidence that the rocks and outcrops suitable for achieving core science objectives (Grotzinger, 2009; Table 1) are present and accessible. While both science and engineering aspects of landing site selection are critical to mission success, the engineering constraints trump science because there is no science return unless the mission lands safely on the surface of Mars. This paper provides a summary of the landing site selection process for the MSL rover with emphasis on the science activities related to selecting the optimal site.

Due to the diverse nature of the Martian surface and quantity of data available, the Mars science community was enlisted to assist in the site selection process via a series of workshops that were open to the science community and public. The process is modeled after the successful Mars Exploration Rover (MER) site selection process

* Corresponding author.
E-mail address: grantj@slu.edu (J.A. Grant).

<http://marsoweb.nas.nasa.gov/landingsites/>

<http://webgis.wr.usgs.gov/msl/>

A link to various proposed science targets
And published papers
related to the final four candidate sites:

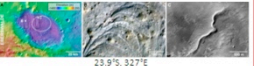


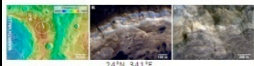
msl.gps.caltech.edu

Summary Paper in
Planetary and Space Science

Outcome of the Fourth Workshop:

Mars Landing Site Selection Activities

Affirmed the high science value of all four candidate sites
"We'd be happy to go to any one of them"

<p>Eberswalde Crater Site</p>  <p>Overarching Hypothesis:</p> <ul style="list-style-type: none">Eberswalde Crater stratigraphy, geomorphology, and mineralogy record the evolution of a crater lake and associated fluvial-deltaic systems, and additionally represent a sedimentary, potentially habitable environment that is favorable to the preservation of organic materials. <p>Specific Cons of Site:</p> <ul style="list-style-type: none">Delta may have been deposited in the early Amazonian or around the time of the Amazonian-Trespanian boundary (unlikely older than late Hesperian)Source and duration of water depositing sediments in delta is uncertain	<p>Specific Pros of Site:</p> <p>Setting:</p> <p>Eberswalde shows excellent preservation of what is highly likely to be a fluvio-deltaic deposit emplaced into a standing body of water that integrated sedimentary material from a broad source region. The landing site provides the opportunity to reconstruct the sedimentary and hydrologic conditions during deposition and specific formation models allow prediction of locations to target for exploration with MSL.</p> <p>Diversity:</p> <p>In addition to the delta-associated deposits, and sinuous ridges in Eberswalde, hills of Holden crater delta megasequence occur in the landing ellipse and provide an exploration target. Collectively, the materials in the ellipse and nearby delta include two distinct low minerals whose distribution is associated with different outcrop characteristics.</p> <p>Preservation:</p> <p>Clay minerals have been found near the bottom of the delta front, maybe in bottom set deposits that form a well-defined target for exploration. There are also potential lake deposits within the landing ellipse that offer exploration targets. Such deposits may concentrate and preserve organic and evidence for habitability and life.</p> <p>Remaining Uncertainties:</p> <ul style="list-style-type: none">Is there evidence of a shoreline/beach in Eberswalde crater corresponding to the elevation of the delta surface and the spillway to the eastern basin? How confident is the interpretation that there are exposed lacustrine sediments and/or bottom set beds in and near the ellipse, and what is their distribution? Could the sulfate lens in Eberswalde crater have been leached out?What time interval is recorded in the deposition of the delta? Could its emplacement be consistent with delivery of water and sediment by the Holden impact? Could the bulk of the sediments forming the delta be Holden spherulites that have been eroded and transported and therefore less likely to record accumulation of organics? Can bottom set beds from each lobe of the delta be defined and identified for exploration? Careful mapping of Eberswalde tributaries and characteristics of incision will help answer these questions.Careful definition of science targets and additional detailed study of mineralogical diversity and scale of the ellipse are needed to help define the exploration strategy for MSL. What specific targets within the database are available for exploration that allow evaluation of conditions during delta emplacement? What are high-priority long-term targets for exploration?
<p>Holden Crater Site</p>  <p>Overarching Hypothesis:</p> <ul style="list-style-type: none">Holden crater preserves evidence of a fluvial-lacustrine system that provides the opportunity to apply a geomorphic systems approach to evaluating a sustained, habitable environment. <p>Specific Cons of Site:</p> <ul style="list-style-type: none">Origin of light-toned layered deposits as lacustrine versus alternate depositional processes remains uncertainAge of light-toned layered deposits and adjacent alluvial fan surfaces may be relatively young at Hesperian and early Amazonian, respectively	<p>Specific Pros of Site:</p> <p>Setting:</p> <p>Fans in the ellipse and light-toned layered deposits comprise one of the largest and best preserved alluvial systems on Mars. The lacustrine and potentially weathered sediments record the conditions responsible for their formation during the Late Hesperian into the Amazonian. This sequence is bounded by the crater floor/wall and overlying lobes. Flood deposits that enable the age of the fans and light-toned layered deposits to be related to global stratigraphy.</p> <p>Diversity:</p> <p>Diversity is represented by fan sediments, phyllosilicate-bearing light-toned layered deposits, upper flood deposits, and magmatic breccia in the crater wall/floor. The mineralogical diversity in the light-toned layered deposits and crater wall/floor include both altered and primary compositions.</p> <p>Preservation:</p> <p>Strata comprising the light-toned layered deposits may be the equivalent of bottom set beds emplaced in a lacustrine setting, which may preserve organics for interrogation by the MSL payload.</p> <p>Remaining Uncertainties:</p> <ul style="list-style-type: none">Are there differences, stratigraphic and/or other properties of the light-toned layered deposits and fan deposits whose distribution can be mapped and used to more confidently define their origin and genetic relationships?A search for additional evidence within the megasequence in the crater wall and floor that can support or refute an impact-induced hydrothermal event would be useful.Better definition of targets for interrogation by MSL is needed within the landing ellipse.
<p>Gale Crater Site</p>  <p>Overarching Hypothesis:</p> <ul style="list-style-type: none">Strata forming the 5 km thick mound of layered sediments within Gale crater reflect a sequence of aqueous habitable environments over an extended time period <p>Possible Cons of Site:</p> <ul style="list-style-type: none">The depositional provenance of the mound strata remains uncertain relative to dominant processes responsible for their emplacement.If deposited in a lake, the relative paucity of associated valleys suggests groundwater as opposed to meteoric sources.Good preservation of crater suggests sediments in mound delivered from outside, unknown provenance(s).The original extent and timing of processes responsible for the current mound form need better definition and the regional and global stratigraphic context of the mound is not firmly established, but may be better resolved by measurement of crater statistics.	<p>Specific Pros of Site:</p> <p>Setting:</p> <p>Diverse stratigraphy in the 5 km mound and adjacent strata, including hydrated minerals, are well defined and the lower mound may reflect deposition during changing environmental conditions, with some contributions by fluvial processes.</p> <p>The landing ellipse contains alluvial materials whose form and distribution record hydrologic conditions when they were emplaced and provides the opportunity to sample materials emplaced and eroded from the crater walls.</p> <p>Diversity:</p> <p>Multiple mineralogical and stratigraphic units within the 5 km thick mound sequence with alternating interbedded clay-rich and sulfate-bearing beds in the lower mound. Stratigraphy comprising the mound is continuous over many km and well characterized in places.</p> <p>Preservation:</p> <p>The phyllosilicate-bearing units in the lower mound and most appear well preserved and may contain and help preserve organics. Biogeochemicals may be preserved in the sulfate-bearing strata in the mound.</p> <p>Remaining Uncertainties:</p> <ul style="list-style-type: none">Can a more detailed evaluation of the strata and mineralogy result in a refined understanding of depositional setting?Can a mass balance of primary vs. degraded crater morphology relative to lower mound volume be used to help resolve the source of the lower mound sediment?Crater statistics may help establish whether the mound is part of a larger deposit and similar to deposits seen elsewhere on Mars and help define how much of Martian history is recorded in the mound.There is the need to define where MSL would go in Gale to look for preserved organics based on geologic and the specific distribution of science targets within the ellipse should be better defined.
<p>Mawrth Vallis Site</p>  <p>Overarching Hypothesis:</p> <ul style="list-style-type: none">Mawrth Vallis records the geologic processes during early Martian history when aqueous phyllosilicate-forming processes were pervasive and persistent, and provides the opportunity to understand early habitability on the planet. <p>Possible Cons of Site:</p> <ul style="list-style-type: none">The timing and depositional setting(s) associated with emplacement of the stratigraphic and mineralogical units at Mawrth remains uncertain as does the amount and duration of interaction with water in development of the units.The relative importance of impact versus alternate processes in emplacement of the stratigraphic and timing of mineralogical units relative to the observed global stratigraphic column remains unclear.	<p>Specific Pros of Site:</p> <p>Setting:</p> <p>Explores the oldest preserved layered stratigraphic section of the four candidate sites and provides an opportunity to explore Mawrth in context to define the processes that were active in early Mars. This stratigraphic sequence may be among the oldest preserved on Mars and may be from a period not recorded in the record on Earth.</p> <p>Current thinking is that the Mawrth sequence formed in a lacustrine environment and the section and near the landing ellipse appears to be mineralogically homogeneous, but with some variation in mineralogy. This allows an understanding of what may have been widespread processes during the Hesperian and younger times on Mars.</p> <p>Diversity:</p> <p>MSL would land on a diverse, complex mineralogical and stratigraphic sequence that records changing processes and environmental conditions. The sequence was likely emplaced by multiple geologic mechanisms that probably included glaciatic, impact, fluvial, and/or pedogenic processes.</p> <p>Preservation:</p> <p>Several locations include proximity with one another and within the ellipse may allow interrogation of a variety of rocks that will help define the early period of time when water was present and determine whether the environment was habitable.</p> <p>Remaining Uncertainties:</p> <ul style="list-style-type: none">The timing and depositional setting(s) associated with emplacement of the stratigraphic and mineralogical units at Mawrth remains uncertain and may be better refined using crater statistics and additional careful mapping.Can the distribution of the units to define a crater sequence be determined to help refine the timing?An important step in resolving the above points involves definition of prioritized targets for interrogation within the ellipse as well as definition of high-priority science targets outside of the ellipse (e.g., for an extended mission). Identification of targets most likely to contain organics is also needed.

Emphasis is squarely on the science of the sites. So an in depth, uniform discussion of key points related to all four sites is required to establish strengths, weaknesses, and remaining uncertainties related to the science interpretation and potential of the sites.